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Influence of mood on visually evoked potentials: a prospective longitudinal study

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Anecdotal observations have suggested that individual differences in mood state could be one reason for the variability of visually evoked potentials (VEP). Therefore, we designed a longitudinal study, in which VEP amplitude was measured and psychological dimensions were assessed. All subjects completed a 'mood state questionnaire' before each session. The results from the VEP measurement and from the mood questionnaire varied widely between subjects. The intraindividual reproducibility, however, was high in 15 of 20 subjects, even over 4 weeks. In some cases we found intraindividual variability of VEP amplitude to be highly correlated with some factors derived from the mood state questionnaire. An overall analysis of covariance and variance (ANCOVA) showed a significant negative correlation between VEP amplitude and the mood factor 'Tiredness' and a significant positive correlation between VEP amplitude and 'Activity'.

INTRODUCTION

Visually evoked potentials (VEP) are a useful tool both for basic vision research and clinical applications (Halliday, 1982; Bach et al., 1988; Regan, 1989). To assess the validity and reliability of VEPs, it is very important to investigate the phenomenon's inter- and intraindividual variability.

In a previous study we unexpectedly found VEP amplitudes to be reduced at all spatial frequencies on some repeated measurements. As a consequence, we checked all parameters in the sessions that produced the unexpected results but found them to be normal. However, upon questioning the subjects, we received subjective information linking low VEP amplitudes with critical life events, such as breakup of a long-lasting relationship, or receiving a nightly threatening phone call, saying "you will be murdered tomorrow". In another case, the reason for the change in mood seemed to be the mental load just before a final examination.

To test any correlation between 'mood' and VEP amplitude, we designed a prospective longitudinal study, quantifying the 'mood' state of our subjects via a psychometric 'mood state questionnaire'.

METHODS

Subjects

We examined 20 subjects, 9 female and 11 male, aged 23 to 67 years. All were paid healthy volunteers, who gave their informed consent to

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participate in the study. 18 of the 20 were naive as to the specific aims of the study. We selected our subjects only on the basis of normal acuity, which was above 1.0 in all cases.

Visual stimulation

Subjects binocularly viewed vertical square-wave gratings, which were presented on a video monitor (frame rate 73 hz, resolution 480 × 391 pixels) and counterphased at a temporal frequency of 7.8 reversals/s. The screen subtended 12° × 15° of visual angle at a distance of 114 cm. The mean luminance of the stimulus was 30 cd/m^2 at 60% contrast. Spatial frequencies ranged from 0.06 to 16 cycles/° and were presented in 12 steps in a counterbalanced order.

Recording

The active electrode position was Oz with reference to Fz (Jasper, 1958), one earlobe was grounded. Potentials were amplified and band-pass filtered (1.5–30 Hz) using a TOENNIES-EEG-machine. A total of 60 sweeps of 512 ms duration were averaged by a small computer (Z80), which also generated the stimuli. To control fixation and accommodation, subjects had to report small digits which appeared for 300 ms in the center of the video monitor. All stimulus conditions were applied at least four times.

Mood questionnaire

The 'SES' mood state questionnaire, developed by the Psycho-physiological Study Group at the University of Freiburg (Hampel, 1977), contains adjective mood scales of 42 items, rated on a five point scale. Six items were scored for 7 factors:

A	Elated mood	
B′	Depressed mood	(inverted: B)
C′	Hostile mood	(inverted: C)
D	Balanced mood	
E′	Inertia	(inverted: E)
F′	Tiredness	(inverted: F)
G	Activity	

For ease of visual inspection, the 'negative' factors B′, C′, E′ and F were inverted: C = 36–C′. This transformation does not influence any statistical inferences.

Procedure

Each subject was examined in eight sessions covering 28 days. Each session started with the questionnaire, which lasted 5–10 min. Subsequent VEP recording lasted 70 min and was followed by an informal interview. Experimental conditions, such as room lighting and time of day, were standardized as much as possible. Many non-visual factors (e.g., weather condition, disturbances during the session, health condition, menstrual cycle, drug use and smoking habits) were documented for each session.

Data analysis

Analysis of the electrophysiological data was based on the magnitude of the stimulus-driven response after a Fourier transformation of the averaged sweeps. For statistical analysis, these VEP amplitudes were tested for normality and found to follow a Gaussian distribution after logarithmic transformation. All further calculations were based on these logarithmic amplitudes and were carried out as an analysis of variance and covariance with repeated measures (ANCOVA) with the aid of the BMDP2V package.

RESULTS

VEP and mood questionnaire measures varied widely between subjects. In some subjects, VEP amplitudes varied little from session to session, in others amplitudes varied greatly. Fig. 1 depicts raw VEP traces covering eight sessions (top to bottom) from two subjects as two extreme examples. The VEP traces show four peaks corresponding to the stimulation rate of 7.8 reversals/s. The subject in the left panel had very similar amplitudes in all sessions, while the subject in the right panel had a wide variability of the VEP amplitude between sessions (low amplitude in the 2nd and 5th session).

As with the electrophysiologic measures, the mood scores varied little in some subjects, while in others they varied widely from session to session. Large within-individual excursions in mood scores were mostly corroborated by information volunteered from the subjects during informal

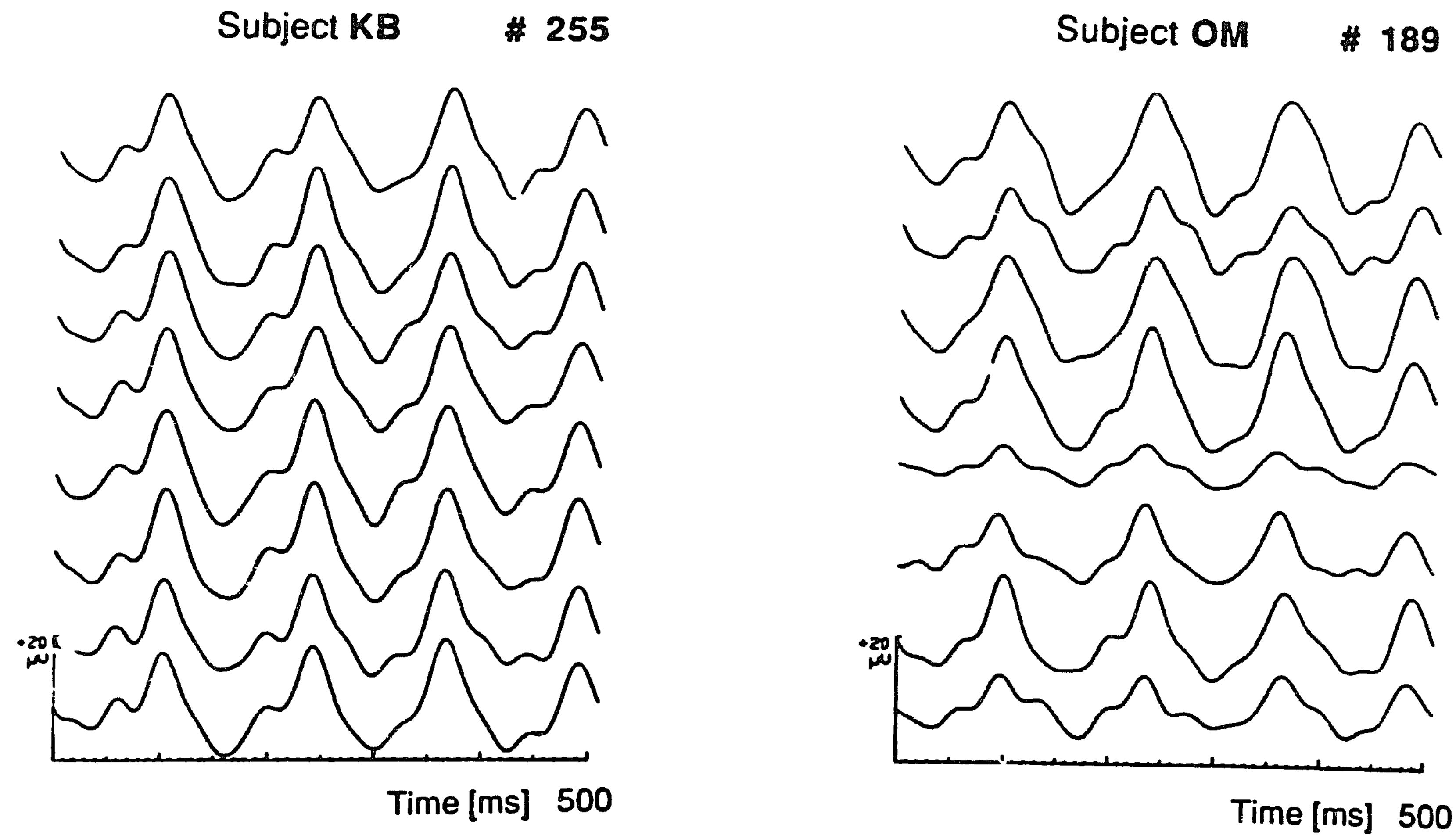

Fig. 1. Original recordings from two subjects (left and right panel). The eight traces from top to bottom represent the steady-state VEP at 2.5 cycles/° over the eight sessions. The subject in the left panel (KB, #255) had very similar amplitudes in all sessions, while the subject in the right panel (OM, #189) showed a wide variability of the amplitude between sessions.

conversation. To compare the time series of mood scores and VEP data, a quantitative measure of the VEP amplitude was defined as the spectral magnitude at the reversal frequency after Fourier analysis of the raw VEP tracings. In Fig. 2, VEP amplitude is plotted vs time over the eight sessions (dashed line). In addition, the scores of the SES factors A (Elated mood), C (Hostile mood) and F (Tiredness) are included (solid lines). Fig. 2 illustrates the typical finding: High variability in

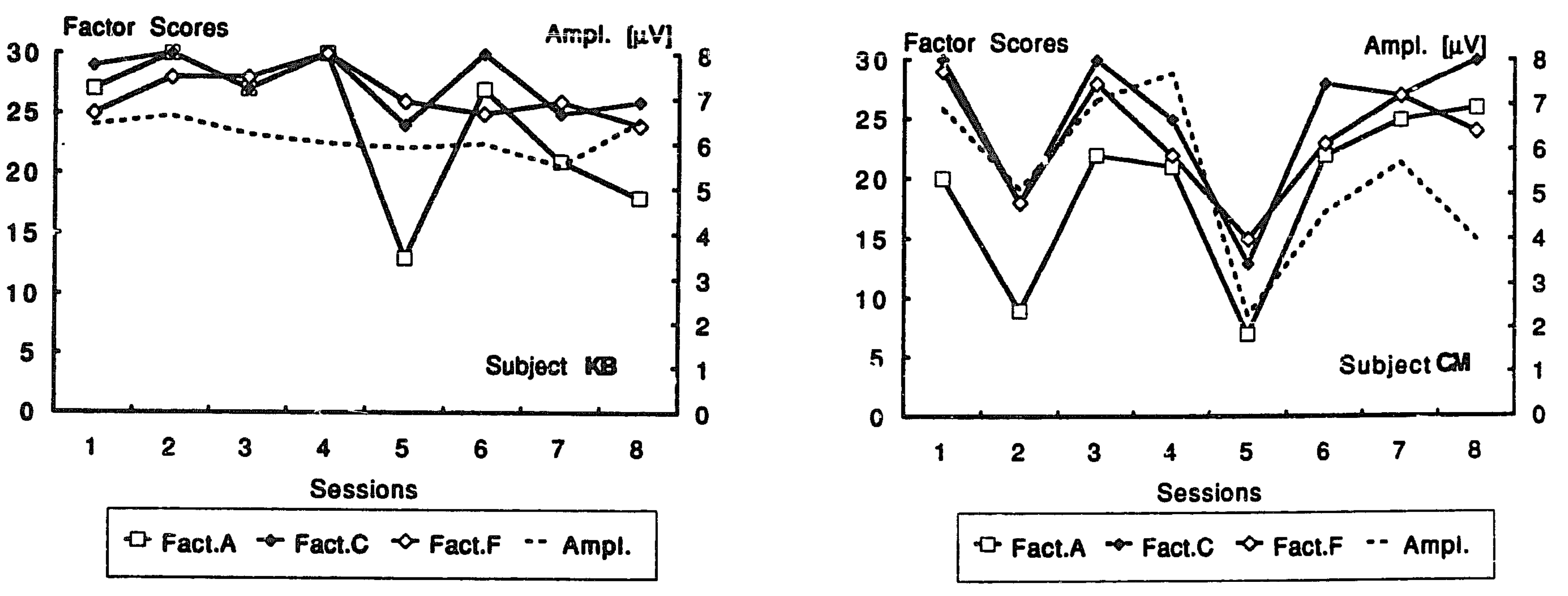

Fig. 2. In both panels VEP amplitude (dashed line) and scores of the SES factors A [Elated mood], C [Hostile mood] and F [Tiredness] (solid lines) are plotted vs time over the eight sessions. Subject KB in the left panel with low amplitude variability had also lower variability in the mood scores as compared to subject OM (right panel).

mood was associated with high variability in amplitude. Furthermore, variation of amplitude was positively correlated with variation of these mood factors. Subject KS (left) with low amplitude variability had also lower variability in the mood scores as compared to subject OM (right). The latter subject reported acute mental load at session 2 and a critical life event (a severe housing problem) at session 5.

Interestingly, depression of VEP amplitude was very similar at all spatial frequencies, as illustrated in Fig. 3. VEP amplitude is plotted with respect to spatial frequency ('tuning curve'; Tyler et al., 1978; Bach and Joost, 1989). Eight such tuning curves from one subject are shown, one for each session. While the exact shape of the tuning curves is known to vary widely between subjects, their intraindividual shape remains fairly constant (low response at very low and very high spatial frequencies, Joost and Bach, 1990; Strasburger et al., 1988). Variability between sessions seems to act like a multiplicative factor, common to all spatial frequencies.

For statistical analysis of any correlation between 'mood' and amplitude, we performed an ANCOVA-test on the data from all subjects and all sessions. As the amplitude variability was common to all spatial frequencies (Fig. 3), we aggregated the amplitude data by summing the amplitudes from all spatial frequencies, omitting the highest and lowest spatial frequencies. The 7 mood scores (A through F) entered the ANCOVA as independent variables, the aggregated logarithmic amplitude as dependent variable. Thus, the ANCOVA analyzed aggregated amplitude × 7 mood scores × subject × session.

This analysis of covariance and variance revealed that the covariance between VEP amplitude and mood scores of all 7 factors reached significance for factor F ($P = 0.0039$). Subsequently, all possible combinations of F with one additional factor were tested. For the factor combination F&G, there resulted a surprisingly high significance level of $P = 0.0020$. All other combinations with factor F showed no significant covariances. The ANCOVA model also included the effect of sequence over the eight sessions. The effect of sequence (e.g., learning) was less significant (P between 0.02 and 0.05 for all combinations) as compared to the effect of mood. The high number of statistical tests must inflate the significance levels to some degree. However, even after the extremely conservative Bonferroni-Holm correction, the results for factor F and for the combination of F&G remain significant on the 5% level.

For visualization of these somewhat abstract analyses, regressions of amplitude vs factor F are plotted in Fig. 4 for all 20 subjects. Obviously, slope varies widely between subjects. In a few cases slope is negative; in others there is a fairly steep rise, indicating a strong influence of mood

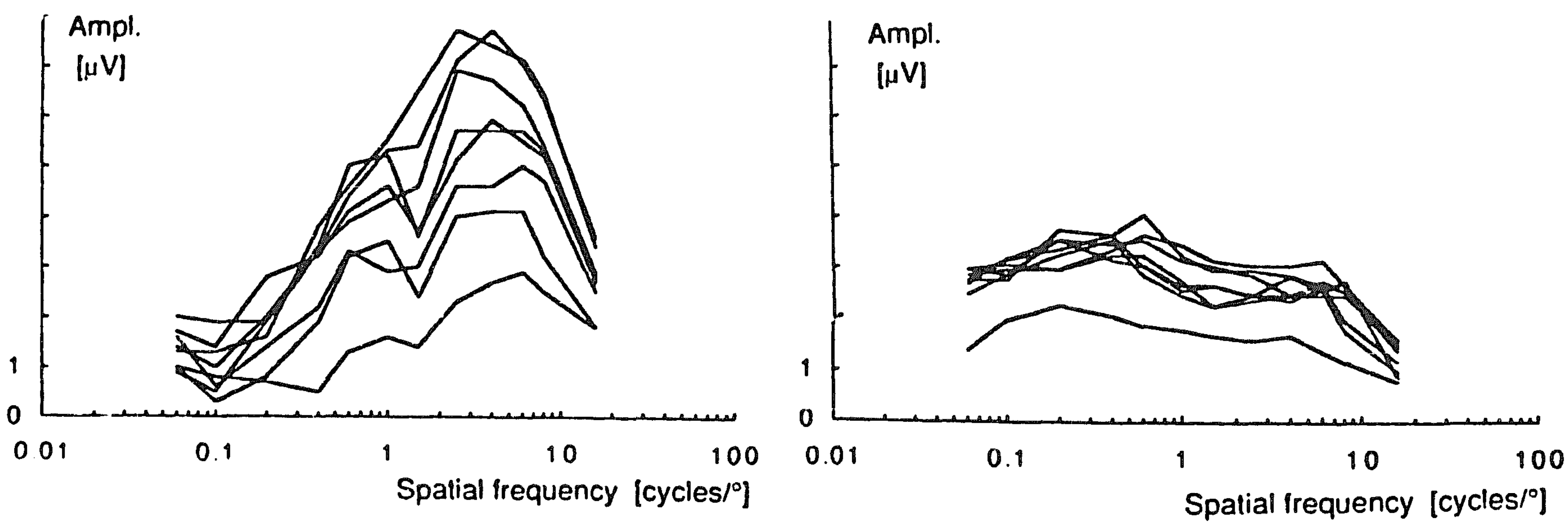

Fig. 3. Tuning curves (amplitude vs spatial frequency) for two subjects over eight sessions. Subject BM (left) had a high inter-session variability for all sessions. For subject AJ (right), the amplitude was reduced in only one session. It can be seen, that relative modulation of VEP amplitude between sessions was similar at all spatial frequencies.

on amplitude. In concordance with the formal analysis above, there is a positive slope in most subjects.

DISCUSSION

Probably every researcher who works with evoked potentials has been, at some time, frustrated by its variability (Meienberg et al., 1979; Harter and Guido, 1980; Yolton et al., 1983; Uren et al., 1979; Lovasik et al., 1985). One major factor causing VEP variability is probably the low signal to noise ratio (Fagan et al., 1984; Bach et al., 1987). The current results suggest that a surprisingly high part of the variability can be attributed to mood in some subjects. Strong mood changes due to major life events can affect the VEP amplitude by more than a factor of two (e.g., Fig. 2). The correlation between 'mood' and amplitude was strong enough to reach a high level of significance, although most of our subjects were very stable in regard to both mood and amplitude over the eight sessions.

What mechanisms may be responsible for 'mood' modulating VEP amplitude? A very simple explanation for the influence of 'mood' could be based on optical factors (Harter and White, 1968; Bach et al., 1985; Lovasik et al., 1985): One could well imagine that subjects in an 'uncooperative mood' would tend to fixate and/or accommodate more poorly. However, we controlled fixation behaviour (see methods), and it did not deviate between sessions, whereas later analysis of the SES questionnaire revealed strong fluctuations in certain mood scores. Furthermore, poor accommodation or defocusing works as an optical two-dimensional low-pass filter and would attenuate VEP amplitudes at high spatial frequencies much more than at lower spatial frequencies (Bach et al., 1989). However, we found that inter-session variability affected the VEP amplitudes at all spatial frequencies similarly (see Fig. 3). Thus, we believe that trivial optical factors

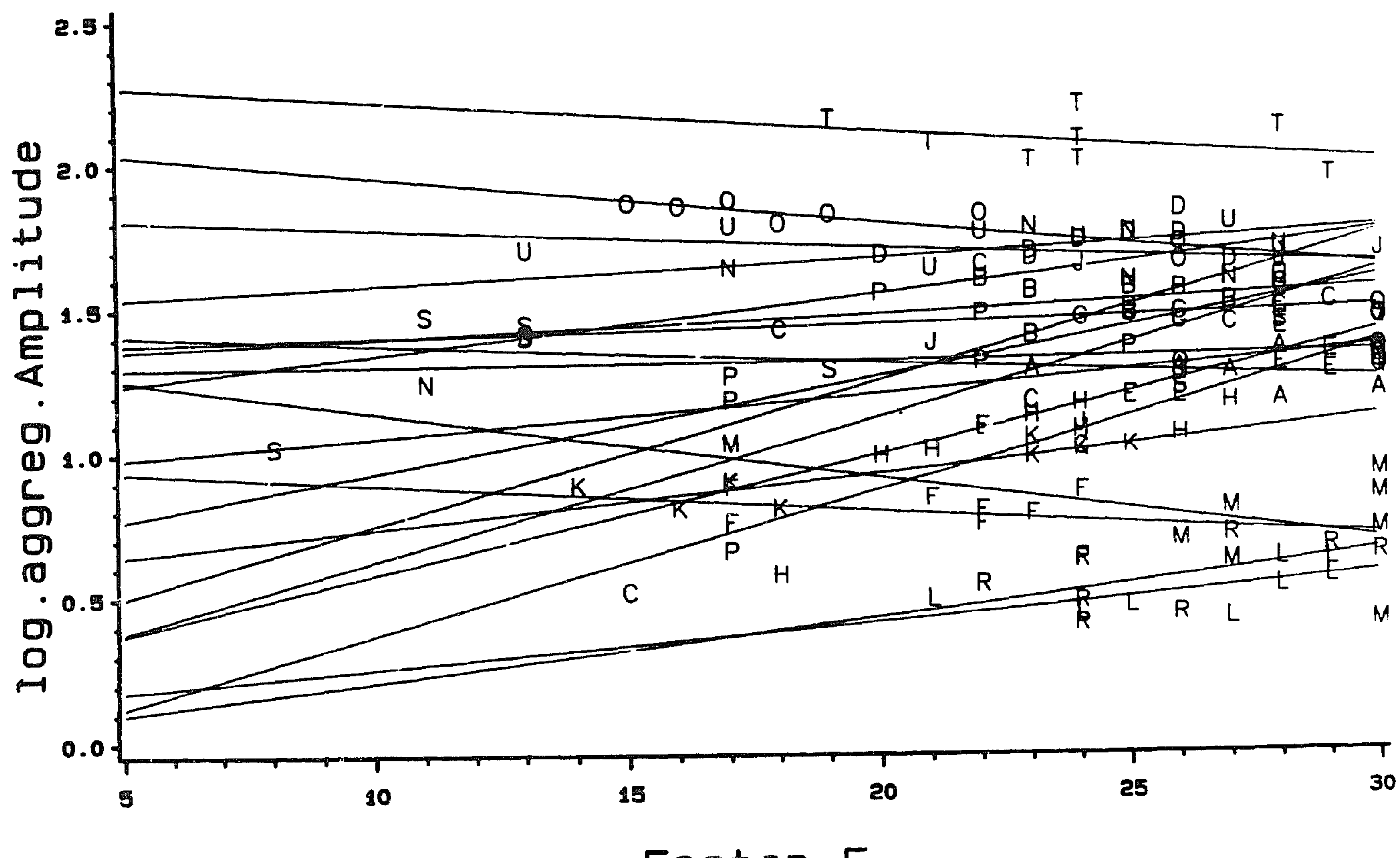

Fig. 4. Original data and regression lines of logarithmic amplitude vs factor F for all 20 subjects. Slope varies widely between subjects. In a few cases slope is negative; in others there is a fairly steep rise, indicating a strong influence of mood on amplitude. In concordance with the formal statistical analysis, there is a positive slope in most subjects.

such as accommodation or fixation behaviour can have played only a minor role in the current experiment. This suggests, that any modulation of VEP amplitude by 'mood' occurs at higher stages in the visual processing chain, starting with the lateral geniculate nucleus as a probable stage.

Circadian rhythms have only a small effect on the VEP (Heninger et al., 1969; Zimmermann et al., 1983). We excluded this factor by carrying out all sessions at the same time of the day.

In those subjects, where both VEP amplitude and mood scores were stable over all sessions, we found little correlation between 'mood' and amplitude. This can be explained in two ways: First, if the variance is low in either variable, any correlation will be buried in the noise of all other influences. Second, it has been suggested, that a mood change has to reach a threshold, before its influence becomes operative (Yolton et al., 1983; Kopp and Gruzelier, 1989). This threshold could be different from subject to subject and may be related to the structure of personality (Lacey and Lacey, 1958; Görtelmeyer and Zimmermann, 1984).

To invoke the term 'attention' (without differentiating between the various psychological constructs in this domain) as an explanation for the intraindividual variability of VEP amplitude does not further our understanding of this problem. There is no generally agreed definition of attention (Posner, 1975). Furthermore, it is a concept that can be studied at many levels (Posner, 1982). In the current experiment, we quantified 'mood' operationally by the SES questionnaire. The factor F (inverted Tiredness) had the highest single covariance with VEP amplitude. This factor F could be related to Posner's (1975) 'alertness' or 'arousal', which characterize the organismic state which affects general receptivity to input information (Posner, 1975).

This paper is an attempt at a wedding of psychophysiology with electrophysiology (Lezak, 1988). We had not expected that the VEP, which we had considered as early sensory processing, might be influenced by psychological factors as 'mood' to such a high degree (if a major life event occurs). We are still far from understanding the specific mechanisms involved. For further examinations, electrodermal activity might be an interesting additional psychophysiological parameter.

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REFERENCES

Bach, M., Bühler, B. and Röver, J. (1987) Selektives Mitteln visuell evozierter Potentiale: Neue Algorithmen und klinische Anwendung. *Fortschr. Ophthalmol.*, 84: 641–645.

Bach, M., Greenlee M.W. and Bühler, B. (1988) Contrast adaptation can increase visually evoked potential amplitude. *Clin. Vision Sci.*, 3: 185–194.

Bach, M. and Joost, W. (1989) VEP vs. spatial frequency at high contrast: Subjects have either a bimodal or single-peaked response function. In: Kulikowski, J.J. and Dickinson, C.M. (Eds.) *Seeing Contour and Colour*. Pergamon Press, Oxford, pp. 478–484).

Bach, M., Waltenspiel, S., Bühler, B. and Röver, J (1985) Sehbahndiagnostik mit simultaner Registrierung der retinalen und kortikalen Musterpotentiale. *Fortschr. Ophthalmol.*, 82: 398–401.

Bach, M., Waltenspiel, S. and Schildwächter, A. (1989) Detection of defocused gratings –Spurious resolution, a pitfall in the determination of visual acuity based on preferential looking and VEP. In: Kulikowski, J.J. and Dickinson, C.M. (Eds.) *Seeing contour and Colour*. Pergamon Press, Oxford, pp. 558–561.

Fagan, J.E., Allen, R.G. and Yolton, R.L. (1984) Factors contributing to amplitude variability of the steady-state visual evoked response. *Am. J. Optom. Physiol. Optics*, 61: 453–464.

Gortelmeyer, R. and Zimmermann, P. (1984) Variability of Evoked-Potential Response to Regularly Repeated Stimulation with Checkerboard Pattern-Reversal and flashlight in Healthy Volunteers. *Neuropsychobiology*, 12: 196–200.

Halliday, A.M. (1982) *Evoked potentials in clinical testing*. Churchill Livingstone, Edinburgh.

Hampel, R. (1977) Adjektiv-Skalen zur Einschätzung der Stimmung (SES). *Diagnostica*, 23: 43–60.

Harter, M.R. and Guido, W. (1980) Attention to pattern orientation: negative cortical potentials, reaction time, and the selection process. *Electroencephalogr. Clin. Neurophysiol.*, 49: 461–475.

Harter, M.R. and White, C.T. (1968) Effects of contour sharpness and check-size on visually evoked cortical potentials. *Vision Res.*, 8: 701–711.

Heninger, G.R., McDonald, R.K., Goff, W.R. and Sollberger, W. (1969) Diurnal Variations in the Cerebral Evoked Response and EEG. *Arch. Neurol.*, 21: 330–337.

Jasper, H.H. (1958) Report on the committee on methods of clinical examination in electroencephalography. *Electroencephalogr. Clin. Neurophysiol.* 10: 370–375.

Joost, W. and Bach, M. (1990) Variability of the steady-state visually evoked potential: Interindividual variance and intraindividual reproducibility of spatial frequency tuning. *Doc. Ophthalmol.*, 75: 59–66.

Kopp, M. and Gruzelier, J. (1989) Electrodermal differentiated subgroups of anxiety patients and controls. II: Relationships with auditory, somatosensory and pain thresholds, agoraphobic fear, depression and cerebral laterality. *Int. J. Psychophysiol.*, 7: 65–75.

Lacey, J.J. and Lacey, B.C. (1958) The relationship of resting autonomic activity to motor impulsivity. *Res. Publ. Assoc. Nerv. Ment. Dis.*, 36: 144–209.

Lezak, M.D. (1988) Neuropsychological tests and assessment techniques. In: Boller, F. and Grafman, J. (Eds.) *Handbook of Neuropsychology*. Vol. 1, Elsevier, Amsterdam, pp. 47–68.

Lovasik, J.L., Spafford, M. and Szymkiw, M. (1985) Modification of pattern reversal VERs by occular accommodation. *Vision Res.*, 25: 599–608.

Meienberg, O., Kutak, L., Smolenski, C. and Ludin, H.P. (1979) Pattern reversal evoked cortical responses in normals. A study of different methods of stimulation and potential reproducibility. *J. Neurol.*, 222: 81–93.

Posner, M.I. (1975) Psychobiology of attention. In: Gazzaniga, M.S. and Blakemore, C. (Eds.) *Handbook of Psychobiology*. Academic Press, New York, pp. 441–480.

Posner, M.I. (1982) Cummulative Development of Attentional Theory. *Am. Psychol.*, 37: 168–179.

Regan, D. (1989) *Human Brain Electrophysiology*. Elsevier, New York.

Strasburger, H., Scheidler, W. and Rentschler, I. (1988) Amplitude and phase characteristics of the steady-state visual evoked potential. *Appl. Optics*, 27:1069–1088.

Tyler, C.W., Apkarian, P. and Nakayama, K. (1978) Multiple spatial-frequency tuning of electrical responses from human visual cortex. *Exp. Brain Res.*, 33: 535–550.

Uren, S.M., Stewart, P. and Crosby, P.A. (1979) Subject co-operation and the visual evoked response. *Invest. Ophthalmol. Vis. Sci.*, 18: 648–652.

Yolton, R.L., Allen, R.G., Goodson, R.A., Schafer, D.L. and Decker, W.D. (1983) Amplitude Variability of the Steady-State Visual Evoked Response (VER). *Am. J. Optom. Physiol. Optics*, 60: 694–704.

Zimmermann, P., Görtelmeyer, R. and Wiemann, H. (1983) Diurnal periodicity of lateral asymmetries of the visual evoked potential in healthy volunteers. *Neuropsychobiology*, 9: 178–181.